# APPENDIX A. SEA-LEVEL RISE SCIENCE AND PROJECTIONS FOR FUTURE CHANGE

## A.1. Global Drivers of Sea-Level Rise

The main mechanisms driving increases in global sea level are: 1) expansion of sea water as it gets warmer (thermal expansion) and 2) increases in the amount of water in the ocean from melting of land-based glaciers and ice sheets as well as human-induced changes in water storage and groundwater pumping (Chao et al., 2008; Wada et al., 2010; Konikow, 2011).[26] The reverse processes can cause global sea level to fall.

## A.2. Local Drivers Sea-Level Rise

Sea level at the regional and local levels often differs from an average global sea level.[27] The primary factors influencing local sea level include tides, waves, atmospheric pressure, winds, vertical land motion and short duration changes from seismic events, storms, and tsunamis. Other determinants of local sea level include changes in the ocean floor (Smith and Sandwell, 1997), confluence of fresh and saltwater, and proximity to major ice sheets (Clark et al., 1978; Perette et al., 2013).

## A.3. Factors Influencing Sea-Level Rise in California

As described above, sea-level rise will vary locally and regionally. Over the long-term, sea level trends in California have generally followed global trends (Cayan et al., 2009; Cayan et al. 2012). The 2012 "Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment" from the California Climate Change Center, assumes "that sea-level rise along the Southern California coast will be the same as the global estimates" (Cayan et al., 2012). The 2011 OPC Interim Guidance on Sea-Level Rise also applied global sea level projections to coastal California, recommending specifically that state agencies consider projections of sea-level rise developed from recent semi-empirical global sea level projections (Vermeer and Rahmstorf, 2009).

However, global projections do not account for California's regional water levels or land level changes. California's water levels are influenced by large-scale oceanographic phenomena such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can increase or decrease coastal water levels for extended periods of time. Figure 7 shows how El Niño and La Niña events have corresponded to mean sea level in California in the past. California's land levels are affected by plate tectonics and earthquakes. Both the changes to water levels and changes to land level are important factors in regionally down-scaled

[26] Large movements of the tectonic plates have been a third major mechanism for changes in global sea level. The time periods for plate movements to significantly influence global sea level are beyond the time horizons used for even the most far-reaching land use decisions. Plate dynamics will not be included in these discussions of changes to future sea level.

[27] For further discussion of regional sea level variations and regional sea-level rise projections, see, for example, Yin et al. 2010, Slangen et al. 2012, Levermann et al. 2013.

projections of future sea level. For these reasons, sea-level rise projections specific to California are more relevant to projects in the coastal zone of California than projections of global mean sea level.

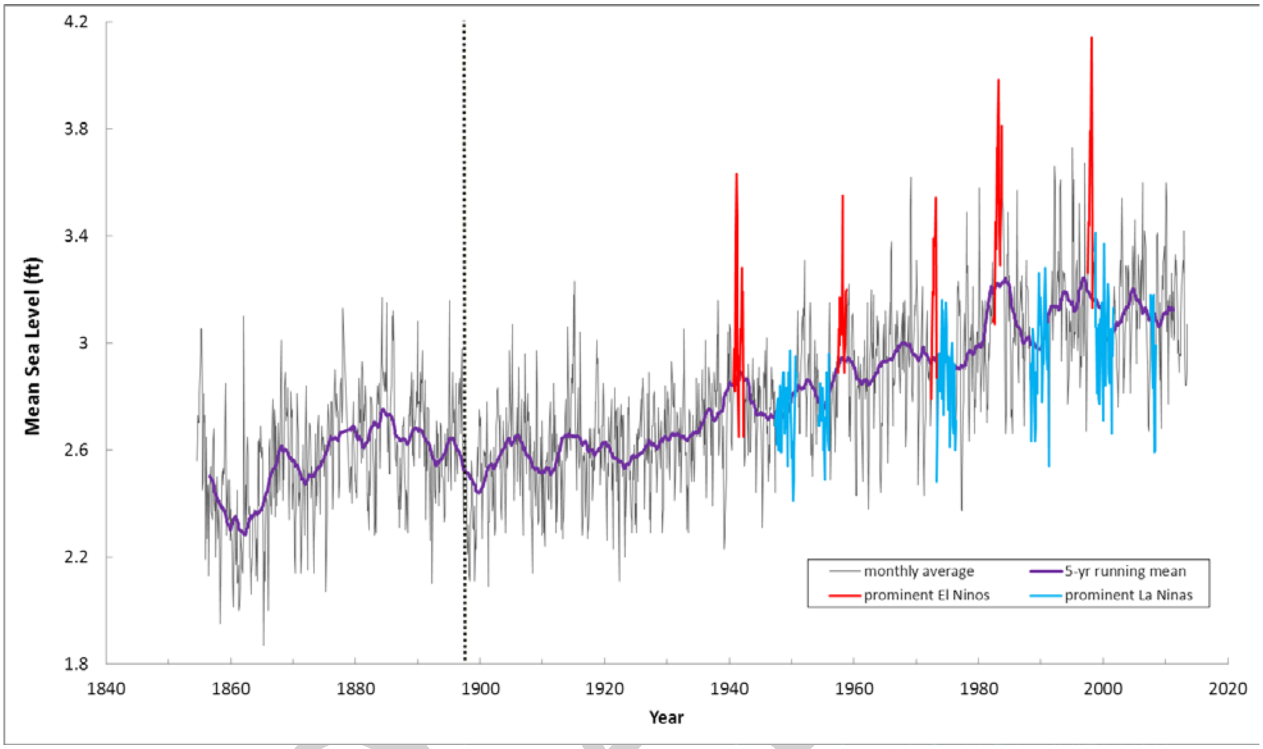


Figure 7. Variations in monthly mean sea level, Fort Point, San Francisco, 1854 to 2013. Mean sea level heights (in feet) are relative to mean lower low water (MLLW). Purple line represents the 5-year running average. Note that the monthly mean sea level has varied greatly throughout the years and the several of the peaks occurred during strong El Niño events (red highlight). Periods of low sea level often occurred during strong La Niña events (blue highlight). The current "flat" sea level condition can also be seen in the 5-year running average. Sources: NOAA CO-OPS data, Station 9414290, http://tidesandcurrents.noaa.gov/ (sea level); NOAA Climate Prediction Center, http://www.elnino.noaa.gov/ (ENSO data).

## A.4. Approaches for Projecting Future Global Sea-Level Rise

This section provides an overview of some of the more well-known approaches that have been used to project sea level changes and their relevance to California. Appendix B will cover how these projections can be used to determine water conditions at the local scale.

There is no single, well-accepted technique for projecting future sea-level rise. Understanding future sea-level rise involves projecting future changes in glaciers, ice sheets, and ice caps, as well as future ground water and reservoir storage. Two subjects in particular present challenges in sea-level rise modeling. First, future changes to glaciers, ice sheets, and ice caps are not well understood and, due to the potential for non-linear responses from climate change, they present many difficulties for climate models (Overpeck, 2006; Pfeffer et al., 2008; van den Broecke et al., 2011; Alley and Joughin, 2012; Shepherd et al., 2012; Little et al., 2013). Second, the actual magnitudes of the two human-induced changes – pumping of groundwater and storage of water in reservoirs – are poorly quantified, but the effects of these activities are understood and can be modeled (Wada et al., 2010). Despite these challenges, sea-level rise projections are needed for many coastal management efforts and scientists have employed a variety of techniques to model sea-level rise, including:

1. Extrapolation of historic trends;
2. Modeling the physical conditions that cause changes in sea level; and
3. Relating sea level to other climatic conditions that can be fairly well projected (empirical or semi-empirical method).[28]

There are strengths and weaknesses to each approach, and users of any sea-level rise projections should recognize that there is no perfect approach for anticipating future conditions. This section provides users of the Guidance document with a general understanding of several of the most widely used sea-level rise projection methodologies and their respective pros and cons. For reference, the 2012 NRC Report, which is considered the best available science at present, used a combination of the latter two techniques.

### A.4.1. Extrapolation of Historic Trends

Extrapolation of historic trends in sea level has been used for many years to project future changes in sea level. The approach assumes that there will be no abrupt changes in the processes that drive the long-term trend, and that the driving forces will not change. Because drivers of climate change and sea-level rise, such as radiative forcing, are known to be changing, this method is no longer considered appropriate or viable in climate science.

A recent modification to the historic trend method discussed above has been to estimate rates of sea-level rise during the peak of the last interglacial (LIG) period (~125,000 years before present, when some drivers of sea-level rise were similar to those today)[29] based on proxy records and apply those sea-level rise rates to the 21$^{st}$ century. For example, Katsman et al. (2011) and Vellinga et al. (2008) used the reconstructed LIG record of sea level change (from Rohling et al., 2008) to reconstruct sea-level rise rates during rapid climate warming, and applied these rates to estimate sea level at 2100 and 2200. Similarly, Kopp et al. (2009) used sea-level rise rates inferred from the LIG to estimate a range of sea-level rise for 2100 between 1.8 – 3.0 feet (0.56 - 0.92 m). Compared to traditional historic trend extrapolation, this modified approach has the advantage of including the dynamic responses of ice sheets and glaciers to past global climates

[28] Another approach to projecting sea-level rise is to use "expert judgment" (AMAP, 2011; Bamber and Aspinall, 2013). The AMAP 2011 report surveyed the literature to construct a range of estimates of SLR by 2100, and then had a panel of experts decide on a smaller "plausible range", which not surprisingly falls right in the middle of the ranges shown in Fig. A-1. Bamber and Aspinall (2013) used statistical analysis of a very large number of expert estimates of future SLR to come up with their projected ranges. This approach will not be discussed further in this section.

[29] During the last interglacial, global mean temperature was 1-2ºC warmer than the pre-industrial era (Levermann et al. 2013), while global mean sea level was likely 5 – 9 m above present mean sea level (Kopp et al. 2009; Dutton and Lambeck 2012; Levermann et al. 2013).

that were significantly warmer than the present, but is limited by the large uncertainties associated with proxy reconstructions of past sea level.

### A.4.2. Physical Models

Physical climate models use mathematical equations that integrate the basic laws of physics, thermodynamics, and fluid dynamics with chemical reactions to represent physical processes such as atmospheric circulation, transfers of heat (thermodynamics), development of precipitation patterns, ocean warming, and other aspects of climate. Some models represent only a few processes, such as the dynamics of ice sheets or cloud cover. Other models represent larger scale atmospheric or oceanic circulation, and some of the more complex General Climate Models (Climate Models) include atmospheric and oceanic interactions.

The Intergovernmental Panel on Climate Change (IPCC) is one of the main sources of peer-reviewed, consensus-based information on climate change. The IPCC does not undertake climate modeling, but uses the outputs from a group of climate models that project future temperature, precipitation patterns, and sea-level rise, based on specific emission scenarios. Seven of the 16 Models used in the IPCC's 4th Assessment Report (2007)[30] provided projections of sea-level rise, and from these models, the IPCC (2007) projected an increase in average global sea level of 7 inches to 23 inches (18 cm to 59 cm) from the time period of 1980 – 1999 to the time period of 2090 – 2099. However, the IPCC elected not to account for dynamic changes in continental ice volume (glaciers and ice sheets) in its sea level projections, stating, *"Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude."* (IPCC 2007, Table SPM-3). The projections include contributions from ice sheet melt based on historical rates of melt, but do not include estimates of sea-level rise change from increased rates of ice sheet melt because there was only limited understanding of such processes at the time of the report (IPCC 2007). As a result, the IPCC projections from the 4th Assessment Report are thought to underrepresent future sea-level rise.

One outcome from the 2007 IPCC report was the realization that there was a need for focused study and modeling of ice dynamics. As an initial effort to better estimate the contributions of ice flows to sea-level rise, climate researchers and glaciologists attempted to determine the upper limit of possible glacier-melt contributions to sea level over several decades, based on the physical constraints of specific glacier systems. A study by Pfeffer, Harper and O'Neel (2008) looked at the plausibility of a rapid rise in sea level from glacial and possible scenarios of polar ice melt. They determined that discharge rates from Greenland glaciers would need to range from 26.8 to 125 km/yr (16.7 to 78 mi/yr), starting immediately and being sustained through 2100, to cause a 2- or 5-m (6.6 to 16.4 ft) rise in sea level by 2100 (Pfeffer et al., 2008). These rates are larger than ever observed even at peak discharges. The researchers do not dismiss the possibility that this discharge could occur, but conclude, "Although no physical proof is offered that the velocities (for a 2- to 5-meter sea-level rise by 2100) cannot be reached or maintained

[30] The most recent Assessment Report as of the time of this document.

over century scales, such behavior lies far beyond the range of observations and at the least should not be adopted as a central working hypothesis" (Pfeffer et al., 2008, pg. 1342). Pfeffer et al. (2008) also project sea-level rise ranging from about 0.8 to 2.0 m (2.6 to 6.6 ft) by 2100, based on the several scenarios of likely ice flow dynamics. This eustatic rise is based on a 0.3 m (1 ft) rise from thermal expansion and between 0.5 to 1.7 m (1.6 to 5.6 ft) from ice dynamics (Pfeffer et al., 2008). Such analysis indicates the importance of ice dynamics in understanding future sea level change.

Focused research on ice dynamics is underway to improve the ability of climate models to address the scale and dynamics of change to glaciers, ice sheets, and ice caps (e.g., Price et al., 2011; Shepherd et al., 2012; Winkelman et al., 2012; Bassis and Jacobs, 2013; Little et al., 2013). Improved modeling will take time to be developed and tested and new models are not expected to be available for several years.

### A.4.3. Semi-Empirical Method

The semi-empirical method for projecting sea-level rise is based on developing a relationship between sea level and some factor (a proxy) –often temperature or radiative forcing– and using this relationship to project changes to sea level. An important aspect of the proxy is that there be fairly high confidence in models of its future changes; a key assumption that is made by this method is that the historic relationship between sea level and the proxy will continue into the future. One of the first projections of this kind was based on the historic relationship between global temperature changes and sea level changes (Rahmstorf, 2007). This semi-empirical approach received widespread recognition with the publication of sea-level rise projections by Rahmstorf (2007). These projections looked at the temperature projections for two of the IPCC emission scenarios that span the likely future conditions within the IPCC framework -- B1, an optimistic, low-GHG emission future and A1FI, a more "business-as-usual" fossil fuel intensive future (See Box on Emissions Scenarios, below).[31] The 2007 projections of sea-level rise were used in the California 2009 Climate Change Scenarios Assessment (Cayan, 2009).

Since the initial semi-empirical projections for future sea-level rise (Rahmstorf, 2007), other researchers have published different projections based on the IPCC scenarios, using different data sets or best-fit relationships.[32] Notably, Vermeer and Rahmstorf (2009) prepared a more detailed methodology that includes both short-term responses and longer-term responses between

[31] When the IPCC began examining climate change, the available models were using a broad range of inputs. In an attempt to evaluate the different model outputs based on the different model characteristics, rather than the inputs, the IPCC developed a number of standard GHG emission scenarios. These scenarios are described in IPCC 1990 Response Strategies Working Group III. In general, the B1 scenario projects the lowest temperature and sea level increases and the A1FI projects the highest increases (IPCC 1990).

[32] Semi-empirical projections of sea-level rise through relationships between water level and radiative forcing such as those from Grinsted et al., 2009, Jevrejeva et al., 2010, Katsman et al. 2011, Rahmstorf et al., 2012, Meehl et al., 2012, Schaeffer et al., 2012 and Zecca & Chiari, 2012 have shown general agreement with the projections by Vermeer and Rahmstorf (2009). The Grinsted et al. projections have a wider range than those from Vermeer and Rahmstorf, while the Jevrejeva et al., projections are slightly lower. All semi-empirical methods project that sea level in 2100 is likely to be much higher than linear projections of historic trends and the projections from the 2007 IPCC.

sea-level rise and temperature. These 2009 projections of sea-level rise were used in the 2010 OPC Interim Guidance on Sea-Level Rise (OPC, 2010) and the California 2012 Vulnerability and Assessment Report (Cayan, 2012).

There are also several new semi-empirical sea-level rise projections based on scenarios other than those developed by the IPCC. For instance, Katsman et al. (2011) use a "hybrid" approach that is based on the one of the newer radiative forcing scenarios and empirical relationships between temperature change and sea level. Future projections were then modified to include contributions from the melting of major ice sheets based on "expert judgment". This yields what they call "high end" SLR projections for 2100 and 2200 under several emissions scenarios.

Zecca and Chiari (2012) produced semi-empirical sea-level rise projections based on their own "fossil fuel exhaustion" scenarios (different scenarios of when fossil fuel resources would be economically exhausted). Though based on a different set of assumptions about human behavior/choices, in terms of global temperature and radiative forcing, the scenarios do not differ greatly from the IPCC scenarios. The results are identified as being "lower bound" sea-level rise projections for high, medium, low fuel use scenarios, and "mitigation" (extreme and immediate action to replace fossil fuel use) scenarios. The report then provides projections for the 2000-2200 time period.

Figure 8 provides a visual summary of several of the more commonly cited projections of future global sea-level rise. The following box provides descriptions of the assumptions used in each of the IPCC AR4 (2007) scenarios.

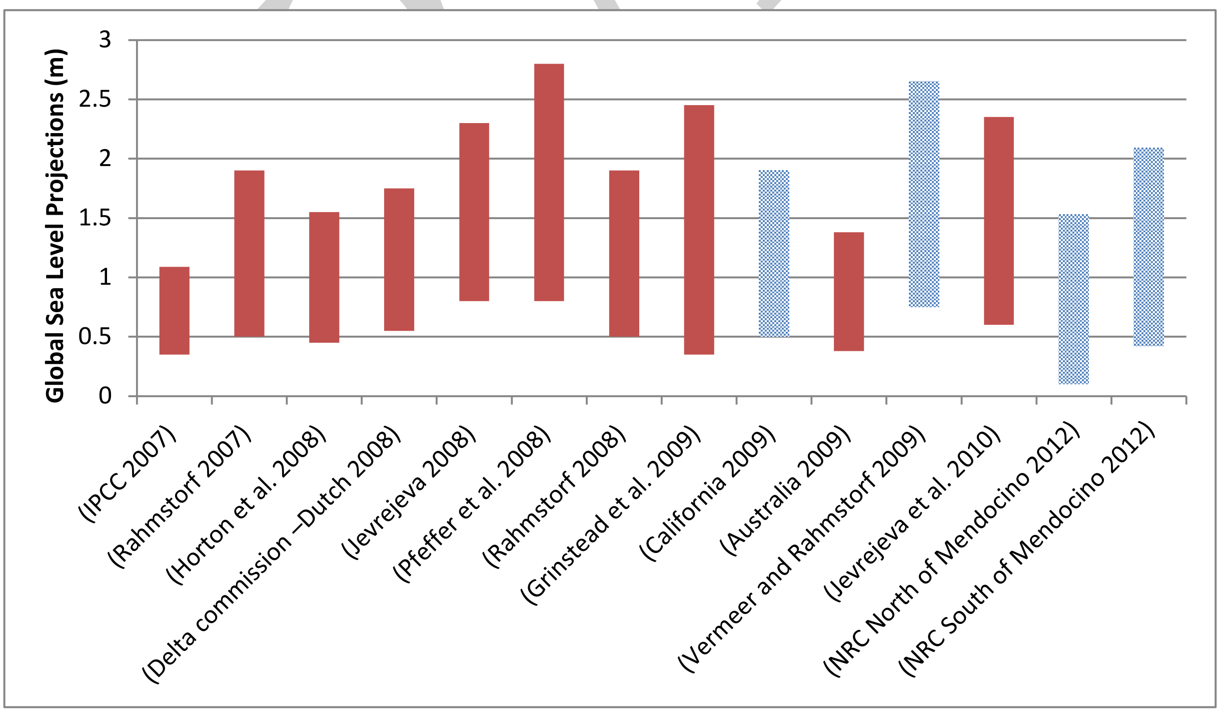


Figure 8. Various 2100 Global Sea-Level Rise Projections. Graphic summary of the range of average global sea-level rise (SLR) projections by end of century (2090–2100) from the peer-

reviewed literature) as compared to the recent National Research Council report for California, Oregon and Washington. The blue patterned boxes indicate projections for California. Ranges are based on the IPCC scenarios, with the low range represented by the B1 scenario (moderate growth and reliance in the future on technological innovation and low use of fossil fuels) and the high part of the range represented by the A1FI scenario (high growth and reliance in the future on fossil fuels). Details on the methods used and assumptions are in the original references.

**The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES)**

**A1**. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system.

The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

**A2**. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

**B1**. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

**B2**. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

(SOURCE: IPCC Special Report on Emissions Scenarios)

## A.5. Recent Projections of Sea-Level Rise and Best Available Science on Sea Level

### A.5.1. National Projections of Sea-Level Rise

Nationwide, the current best available science on sea-level rise projections is the Global Sea Level Rise Scenarios Report for the United States National Climate Assessment (NOAA, 2012). The report provides a set of four scenarios of future global sea-level rise, as well as a synthesis of the scientific literature on global sea-level rise. The NOAA Climate Program Office produced the report in collaboration with twelve contributing authors.[33] The report includes the following description of the four scenarios:

- **Low scenario:** The lowest sea level change scenario (8 inch rise) is based on historic rates of observed sea level change.
- **Intermediate-low scenario:** The intermediate-low scenario (1.6 feet) is based on projected ocean warming.
- **Intermediate- high scenario:** The intermediate-high scenario (3.9 feet) is based on projected ocean warming and recent ice sheet loss.
- **High scenario:** The highest sea level change scenario (6.6 feet) reflects ocean warming and the maximum plausible contribution of ice sheet loss and glacial melting. This highest scenario should be considered in situations where there is little tolerance for risk (NOAA, 2012).

The NOAA 2012 report provides steps for planners and local officials to modify these scenarios to account for local conditions. These steps are intended for areas where local sea-level rise projections have not been developed. For California, the NRC report (below) provides scenarios that have been refined for use at the local level, and the Coastal Commission, along with the State of California Sea Level Rise Guidance, recommends using the NRC projections rather than the global scenarios.

### A.5.2. California-Specific Projections of Sea-Level Rise and Best Available Science

The National Research Council (NRC) Committee on Sea-Level Rise in California, Oregon and Washington (NRC Committee) recently released a report on regional sea-level rise trends and projections of future sea level change for California, Oregon and Washington. This report provides a broad examination of sea level for the California coast and currently represents the best available science on the topic. The NRC Committee investigated both the global and regional sea level projections, taking a different track than earlier efforts to develop sea-level rise projections both globally and for the California coast. The NRC Committee started with several of the basic scenarios that have been the foundation of the IPCC climate projections and the

[33] Authors include NOAA, NASA, the U.S. Geologic Survey, the Scripps Institution of Oceanography, the U.S. Department of Defense, the U.S. Army Corps of Engineers, Columbia University, the University of Maryland, the University of Florida, and the South Florida Water Management District.

earlier climate projections for California. They combined projections of steric changes (thermal expansion or contraction) with changes in the amount of ocean water due to melting of land-based ice on Greenland and Antarctica, as well as contributions from other land-based glaciers and ice caps. Table 5 shows the NRC projections for *global* sea-level rise.

Table 5. Recent Global Sea-Level Rise Projections for 2000 to 2100

| Time Period | NRC Report, 2012 (Metric) | | NRC Report, 2012 (English) | |
|---|---|---|---|---|
| | Average | Range | Average | Range |
| 2000 – 2030 | 13.5 ± 1.8 cm | 8.3 – 23.2 cm | 5.3 ± 0.7 inch | 3.3 – 9.1 inch |
| 2000 – 2050 | 28 ± 3.2 cm | 17.6 – 48.2 cm | 11 ± 1.3 inch | 6.9 – 19.0 inch |
| 2000 – 2100 | 82.7 ± 10.6 cm | 50.3 – 140.2 cm | 32.6 ± 4.2 inch | 19.8 – 55.2 inch |

Source: NRC, 2012

After developing the global sea-level rise projections, the NRC Committee modified the global projections based on the influence of polar ice and regional changes in uplift and subsidence to create sea-level rise projections for California specifically. The NRC Committee identified distinctly different land level changes north and south of Cape Mendocino. The area north of Cape Mendocino is experiencing significant uplift of about 1.5 to 3 mm/yr (0.059 to 0.118 inches/yr) that the Committee attributed to plate movement along the Cascadia Subduction Zone (NRC, 2012, p. 93). In contrast, the coast south of Cape Mendocino is dropping at an average rate of about 1 mm/yr (0.039 inches/yr) (NRC, 2012, p. 93). The measurements of land subsidence south of Cape Mendocino vary widely, from -3.7 mm/yr to +0.6 mm/yr (-0.146 inches/yr to + 0.024 inches/yr) (NRC, 2012, p. 93), with slightly greater subsidence in southern California than in Central California.[34] The NRC Committee noted that the uplift being experienced along the Cascadia Subduction Zone may reverse during a fault rupture or earthquake of magnitude 8.0 or greater along the Cascadia Subduction Zone. The NRC report notes that during a large earthquake (magnitude 8 or greater), coastal areas could experience sudden vertical land motion, with uplift in some locations and subsidence as much as 6.6 feet (2 meters) in other locations (NRC, 2012). Despite the rapid reversibility of much of the coastal uplift north of Cape Mendocino, the NRC Report provided projections of regional sea level through 2100 that incorporate land uplift. Table 6 shows the regional projections of sea-level rise from the NRC Report.

[34] Personal Communication to staff from Anne Linn, NRC Study Director (August 1, 2012)

Table 6. California Sea-Level Rise Projections for 2000 to 2100

| Time Period | NRC Report 2012 | |
|---|---|---|
| | North of Cape Mendocino[35] | South of Cape Mendocino |
| 2000 – 2030 | -4 – +23 cm (1.6 – +9.0 inch) | 4 – 30 cm (1.6 – 12 inch) |
| 2000 – 2050 | -3 – + 48 cm (-1.0 – +19.0 inch) | 12 – 61cm (5 – 24 inch) |
| 2000 - 2100 | +10 – +143 cm (+4 – +56 inch) | 42 – 167 cm (16.5 – 66 inch) |

Source: NRC, 2012.

The NRC report also provides sea-level rise projections for four individual coastal communities that have long-term tide gauge records, including San Francisco and Los Angeles. These projections match the regional projections for south of Cape Mendocino to within a few millimeters, demonstrating that the regional projections track closely with more localized projections. The NRC report provides no information about the appropriate coastal section that might be included with either the San Francisco or Los Angeles projections. Due to the lack of direction about how to use the localized projections and their close fit with the regional values, the NRC scientists recommend using the regional values, with the exception of parts of Humboldt Bay and the Eel River estuary, unless the area in question is very close to either San Francisco or Los Angeles.

### A.5.3 Findings from 2012 NRC Report on Natural Shoreline Responses to Sea-Level Rise

Rising sea level will accelerate many of the flooding and erosion conditions that are already putting coastal development and infrastructure at risk. Some of the key findings about impacts to natural shorelines throughout California from the NRC report include:

- **Bluffs and cliffs:** Sea-level rise will lead to an increase in bluff erosion and bluff retreat because more wave energy will be available to erode cliffs and bluffs. Waves will break closer to the coastline and will reach the base of the cliff or bluff more frequently, increasing the rate of retreat. Current responses such as armoring bluffs will be less effective as overtopping occurs more frequently.

- **Beaches:** Sea-level rise will cause landward migration or retreat of beaches over the long term. Beaches with seawalls or other barriers will not be able to migrate landward and the sandy beach areas will gradually become inundated.

- **Coastal dunes:** Sea-level rise will cause dunes to retreat quickly.

[35] With the exception of parts of Humboldt Bay and the Eel River Estuary which are experiencing subsidence and therefore a higher rate of sea-level rise than projected for the region.

- **Changing retreat rate:** The report finds that extrapolation of current erosion rates until 2030 is a reasonable approach. Beyond 2030, the report recommends that an unspecified "safety factor" should be added to existing trends to accommodate future sea-level rise and potential increases in storm wave heights.

- **Estuaries and tidal marshes:** Sea-level rise may affect the tidal dynamics within the estuary, including the tidal range. The transition from intertidal flats to marshes is especially sensitive to changes in sea level, depending on salinity and inundation tolerance limits of vegetation. Marshes will migrate inland if land is available and the marsh is able to build in elevation at a rate that keeps pace with sea-level rise. Estuaries and marshes that have adequate space to migrate can buffer the impacts of sea-level rise to built environments.

- **Coastal sediment supplies:** Supplies of sediment to the coast will be important for survival of wetlands and tidal marshes, and to a lesser extent, of beaches during rising sea level. Through 2050, frequent storms that promote sediment deposition could allow marshes to survive; by 2100 only areas of high sediment supplies may support viable marsh habitat if the higher range of sea level is experienced. In northern California, water management practices will also be important for long-term marsh survival.